

Program 11 Inelastic Response of Metal Matrix Composites Under Biaxial Loading

C.J. Lissenden, F. Mirzadeh, M.-J. Pindera and C.T. Herakovich

Objectives

The long-term objective of this investigation is aimed at attaining a complete understanding of the inelastic response of metal matrix composites subjected to arbitrary, biaxial load histories. The core of the research program is a series of biaxial tests conducted on different types of advanced metal matrix composite systems using the combined axial/torsional hydraulic load frame in the Composite Mechanics Laboratory at the University. These tests involve primarily tubular specimens and include tension, compression, torsion and combinations of the above load histories in order to critically assess the inelastic response of advanced metal matrix composites in a wide temperature range.

## Inelastic Response of SCS-6/Ti-15-3 Metal Matrix Composite

C. J. Lissenden, C. T. Herakovich & M-J Pindera

### ABSTRACT

Theoretical predictions and experimental results have been obtained for inelastic response of unidirectional and angle-ply composite tubes subjected to axial and torsional loading. The composite material consists of silicon carbide fibers (40% fiber volume fraction) in a titanium alloy matrix. This particular material system is known to be susceptible to fiber/matrix interfacial damage. A method to distinguish between matrix yielding and fiber/matrix interfacial damage is suggested.

Biaxial tests have been conducted on the two different layup configurations using an MTS Axial/Torsional load frame with a PC based data acquisition system. To date two  $[0_4]$  tubes and one  $[\pm 45]_s$  tube have been tested. The experimentally determined elastic moduli of the SiC/Ti system are compared with those predicted by a micromechanics model. The test results indicate that fiber/matrix interfacial damage occurs at relatively low load levels and is a local phenomenon.

The micromechanics model used is the method of cells originally proposed by Aboudi. This model has the capability to generate the effective response of metal matrix composites in the linear and inelastic range in the presence of imperfect bonding between the fiber and matrix. The model has also been used to determine initial yield surfaces for comparison with experimental results and as a guide in the selection of the biaxial loadings to be considered.

Finite element models using the ABAQUS finite element program have been employed to study end effects and fixture/specimen interactions. The finite element studies have shown large stress concentrations near the fixtures.

The results to date have shown good correlation between theory and experiment for response prior to the initiation of damage. The correlation is less satisfactory after damage occurs. Damage is evident in the tests from the stress-strain results and audible acoustic events. Damage has been observed to occur before the onset of matrix yielding.

Low axial strength obtained for the  $[0_4]$  tube has been attributed to the stress concentrations associated with the fixture.

# Inelastic Response of SCS-6/Ti-15-3 Metal Matrix Composite

by

C.J. Lissenden  
C.T. Herakovich  
M.J. Pindera

NASA Technical Monitor:

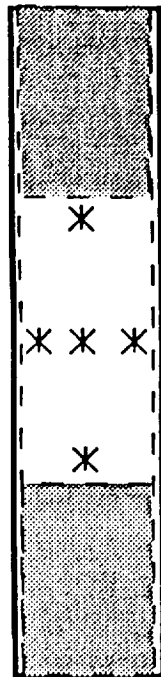
W.S. Johnson

July, 1991



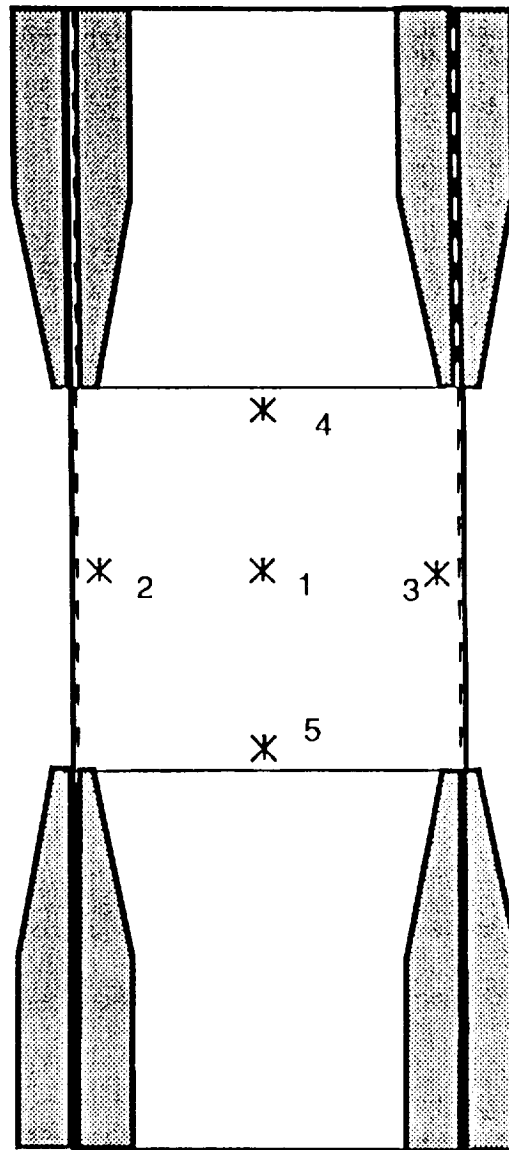
UVA  
APPLIED  
MECHANICS

# NOMINAL TUBE GEOMETRY



$[0]_4$

\* = S.G.



$[+45]_s$

0.718	Ri(in)	1.968
0.750	Ro(in)	2.000
0.148	A(sq in)	0.399
0.0795	J(in <sup>4</sup> )	1.570
0.4	$\nu_f$	0.4



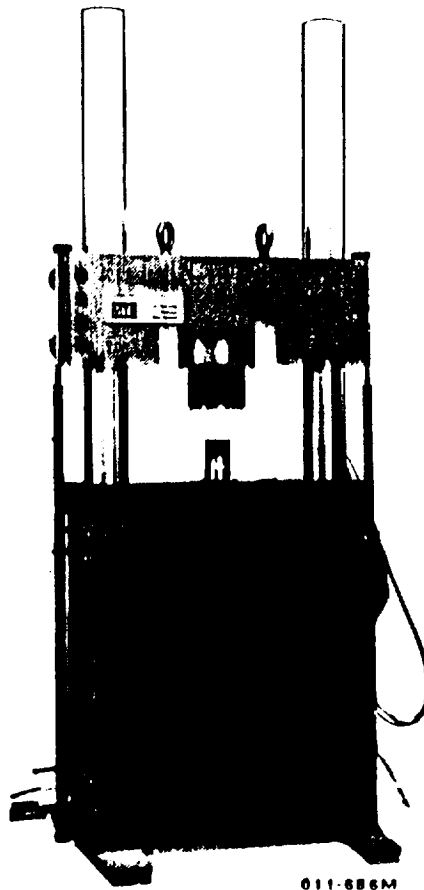
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MECHANICS

# SCS-6/Ti-15-3 Tube Manufacturing Process

1. Lay fibers flat
2. Weave fibers and 2 mil molys
3. Wrap foil around mandrel
4. Wrap fiber cloth around foil
5. Continue laying up foil and fiber cloth
6. Enclose in steel tube
7. Hot press at 1800 ° F and 15 ksi
8. Cool
9. Machine
10. Dip in liquid bath



# SERIES 319 AXIAL TORSIONAL LOAD UNIT



011-686M



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## PREDICTED ELASTIC PROPERTIES

Perfect Bond ( $R_n = 0, R_t = 0$ )

	$E_{xx}$ (msi)	$G_{xy}$ (msi)	$G_{12}$ (msi)	$\nu_{xy}$
$[0]_4$	31.2	7.92	----	0.313
$[+45]_s$	23.3	10.50	7.86	0.375

Total Debond ( $R_n = 0.01, R_t = 0.1$ )

	$E_{xx}$ (msi)	$G_{xy}$ (msi)	$G_{12}$ (msi)	$\nu_{xy}$
$[0]_4$	31.2	1.79	----	0.360
$[+45]_s$	6.0	8.1	1.8	0.70



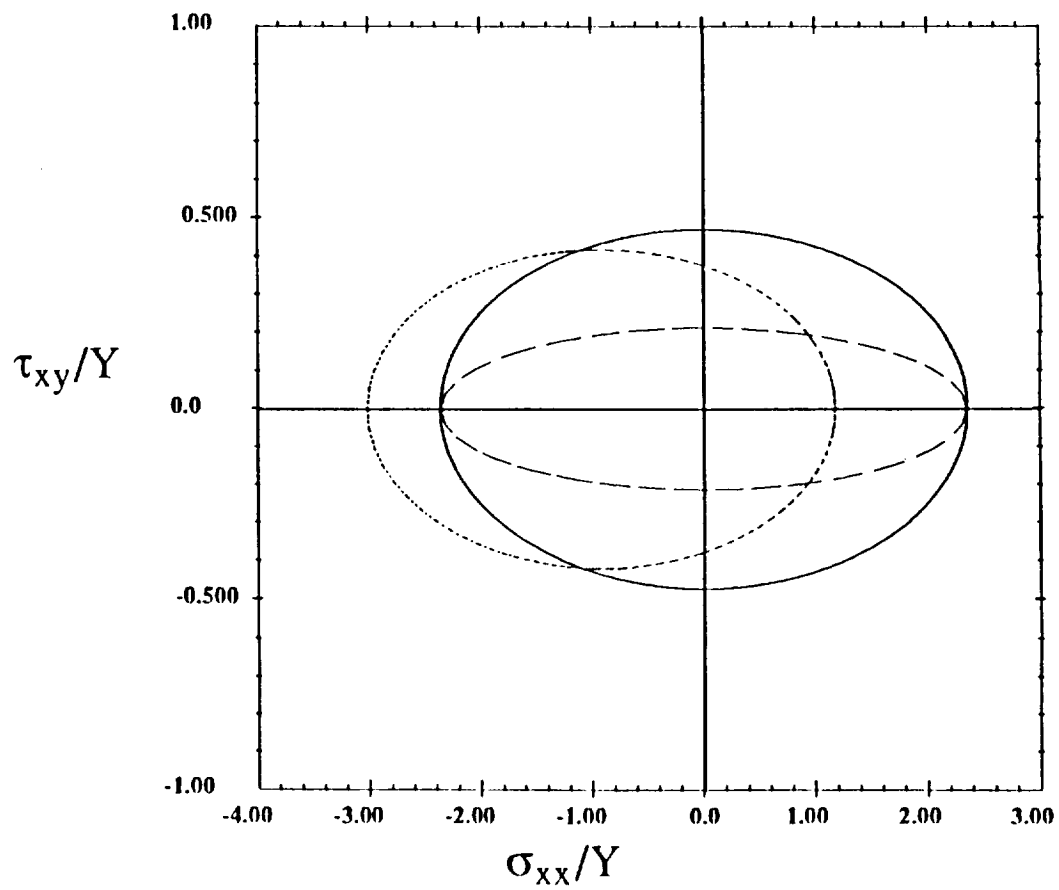
# SCS-6/Ti 15-3

$[0]_4 V_f=0.4$

—  $R_n=0, R_t=0$

.....  $\Delta T=-1800^\circ\text{F}, R_n=0, R_t=0$

- - -  $R_n=0.01, R_t=0.1$



no zero plot



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# SCS-6/Ti 15-3

$[\pm 45^\circ]_s, V_f=0.4$

—

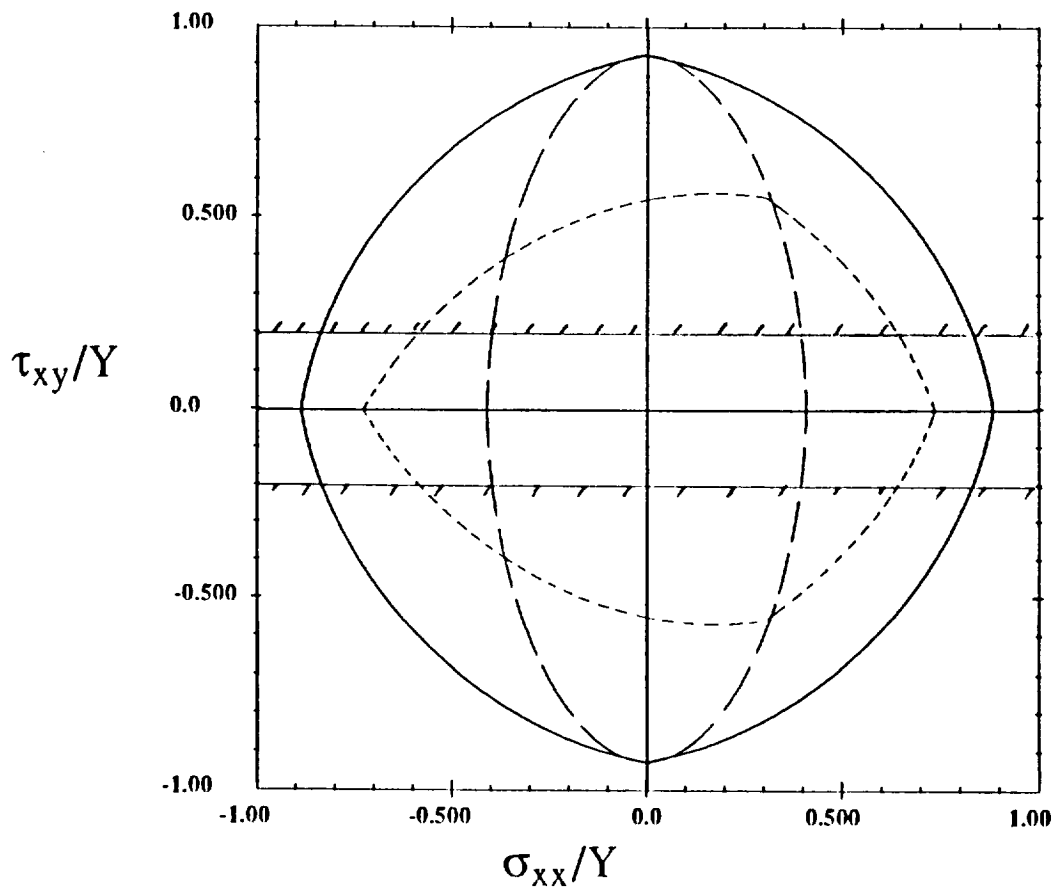
$R_n=0, R_t=0$

.....

$\Delta T=-1800^\circ\text{F}, R_n=0, R_t=0$

- -

$R_n=0.01, R_t=0.1$



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MECHANICS

# SCS-6/Ti-15-3

## as a

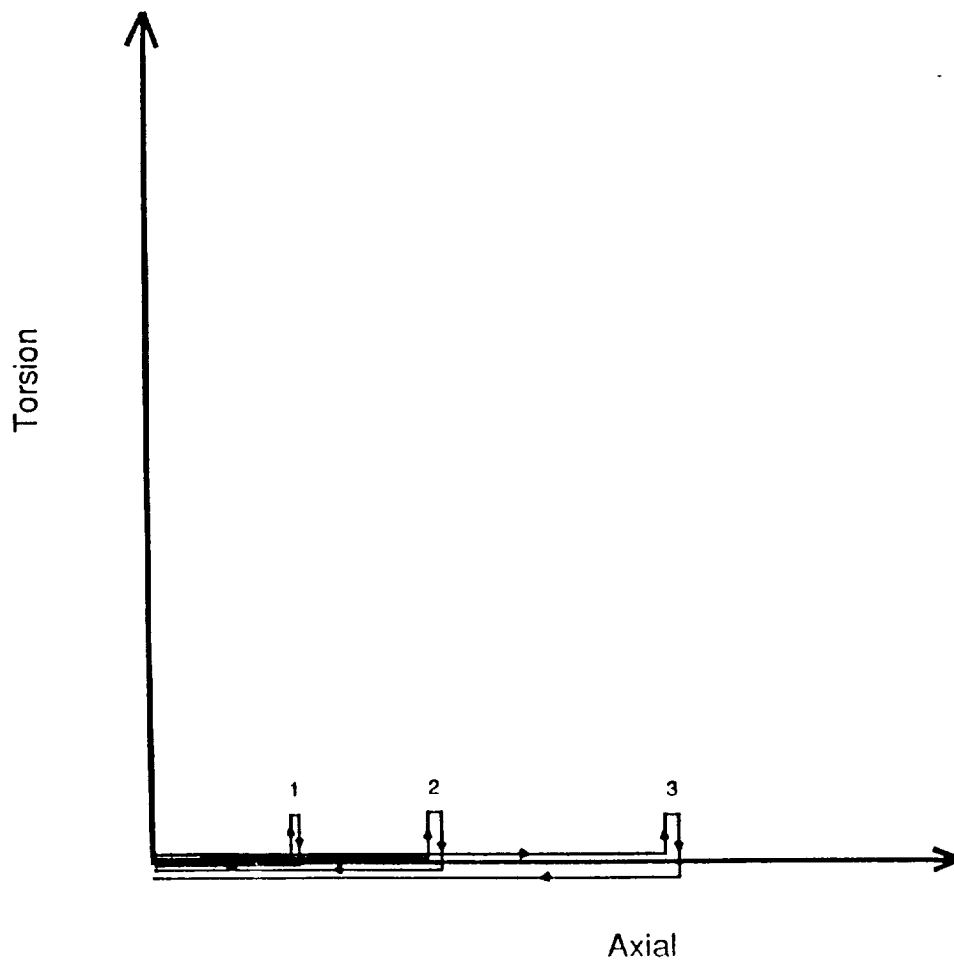
### Three Phase Composite

- Theoretical Volume Fractions

— SCS-6	39.4%
— Ti-15-3	60.4%
— Molybdenum	0.2%



## TEST METHOD

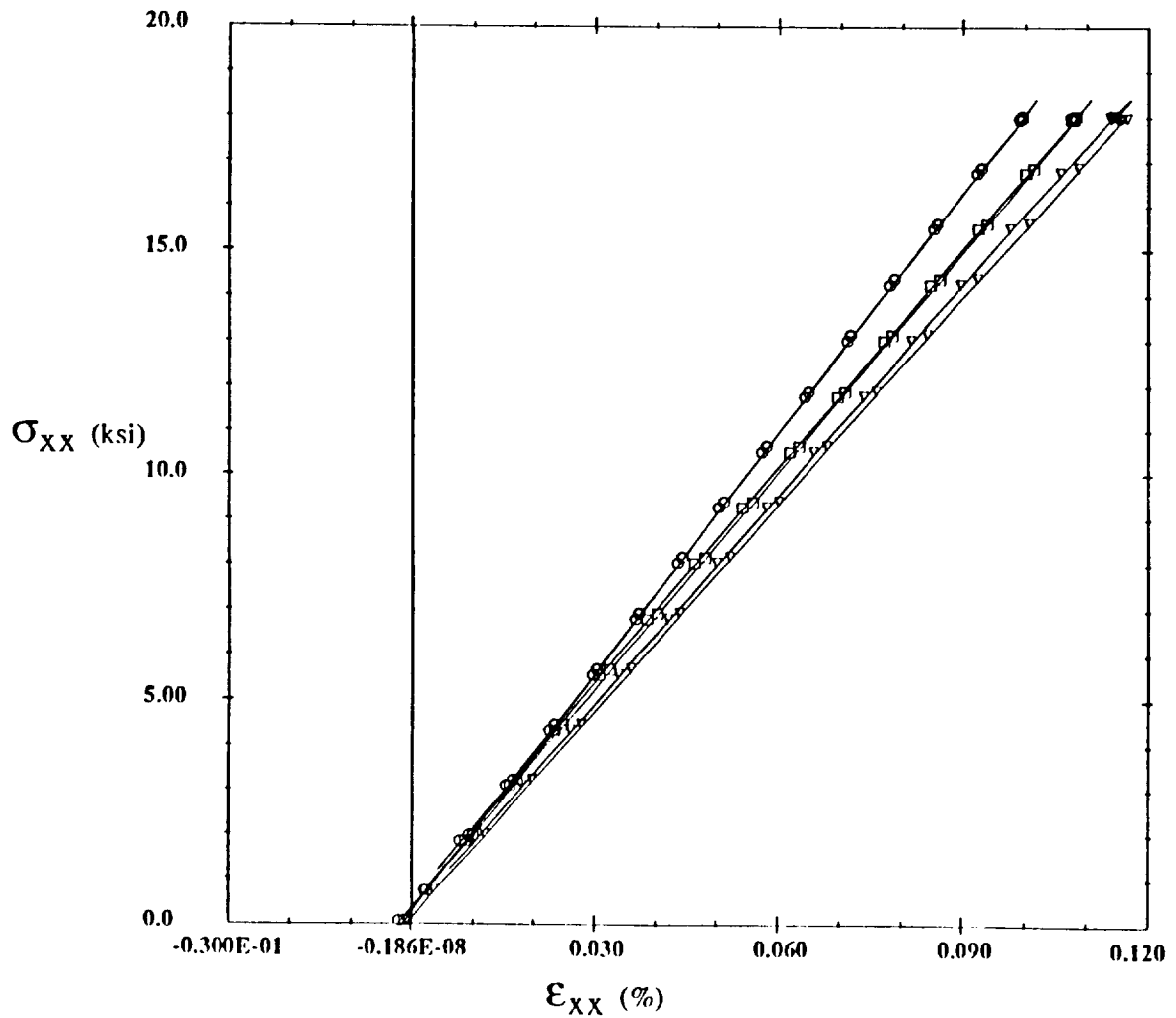


# SCS-6/Ti 15-3 Axial Stress/Strain

( $\pm 45$ )<sub>s</sub>  $\nu_f=0.4$

Speciman#5 Test#9

- ▽— Rosette#1  $E_{xx}=15.4\text{msi}$
- Rosette#2  $E_{xx}=16.2\text{msi}$
- Rosette#3  $E_{xx}=17.7\text{msi}$



nam 59 plot



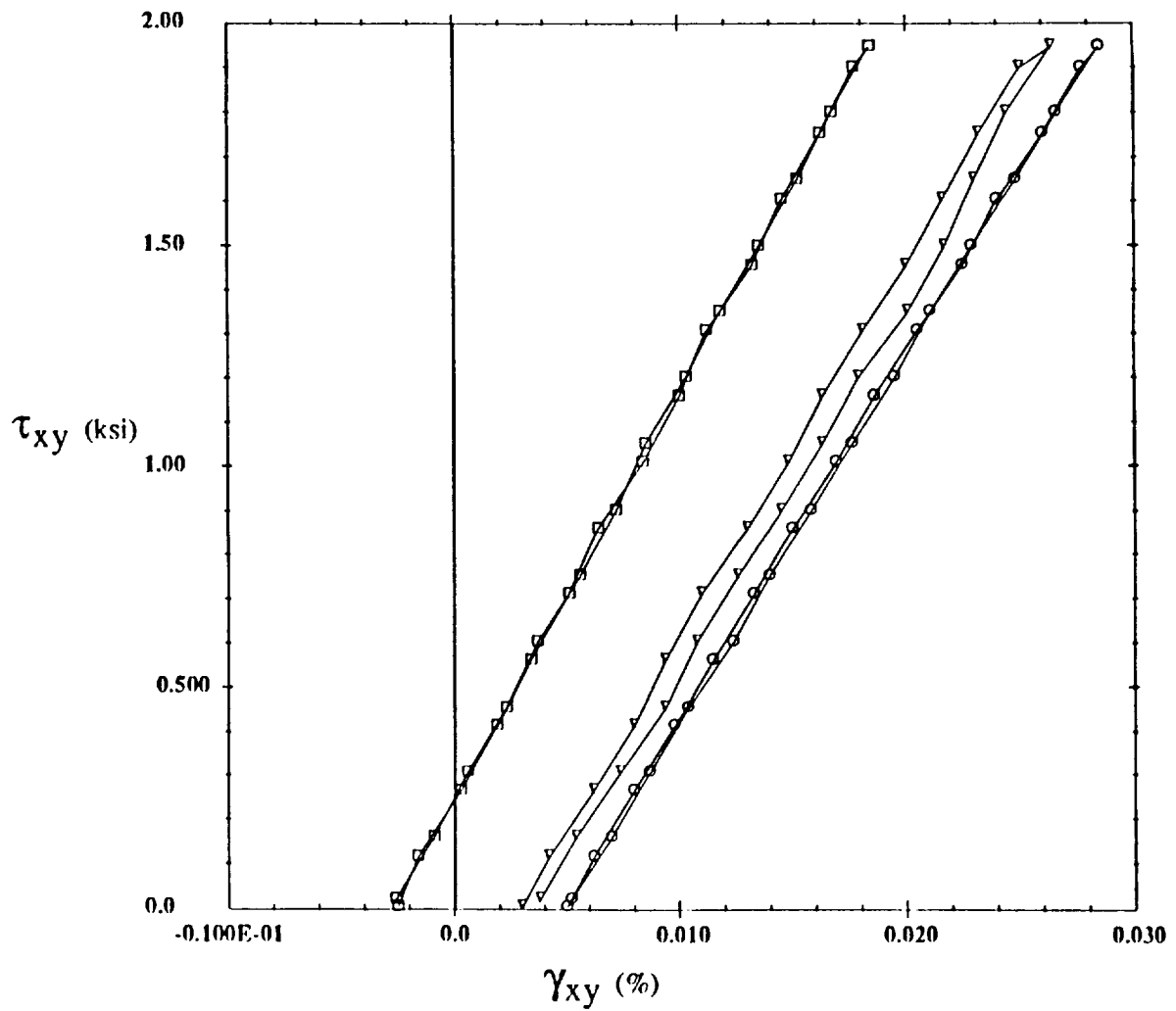
UVA  
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MECHANICS

# SCS-6/Ti 15-3 Shear Stress/Strain

( $\pm 45$ )<sub>s</sub>  $\nu_f = 0.4$

Speciman#5 Test#9

- ▽— Rosette#1  $G_{xy} = 8.52 \text{ msi}$
- Rosette#2  $G_{xy} = 9.29 \text{ msi}$
- Rosette#3  $G_{xy} = 8.33 \text{ msi}$

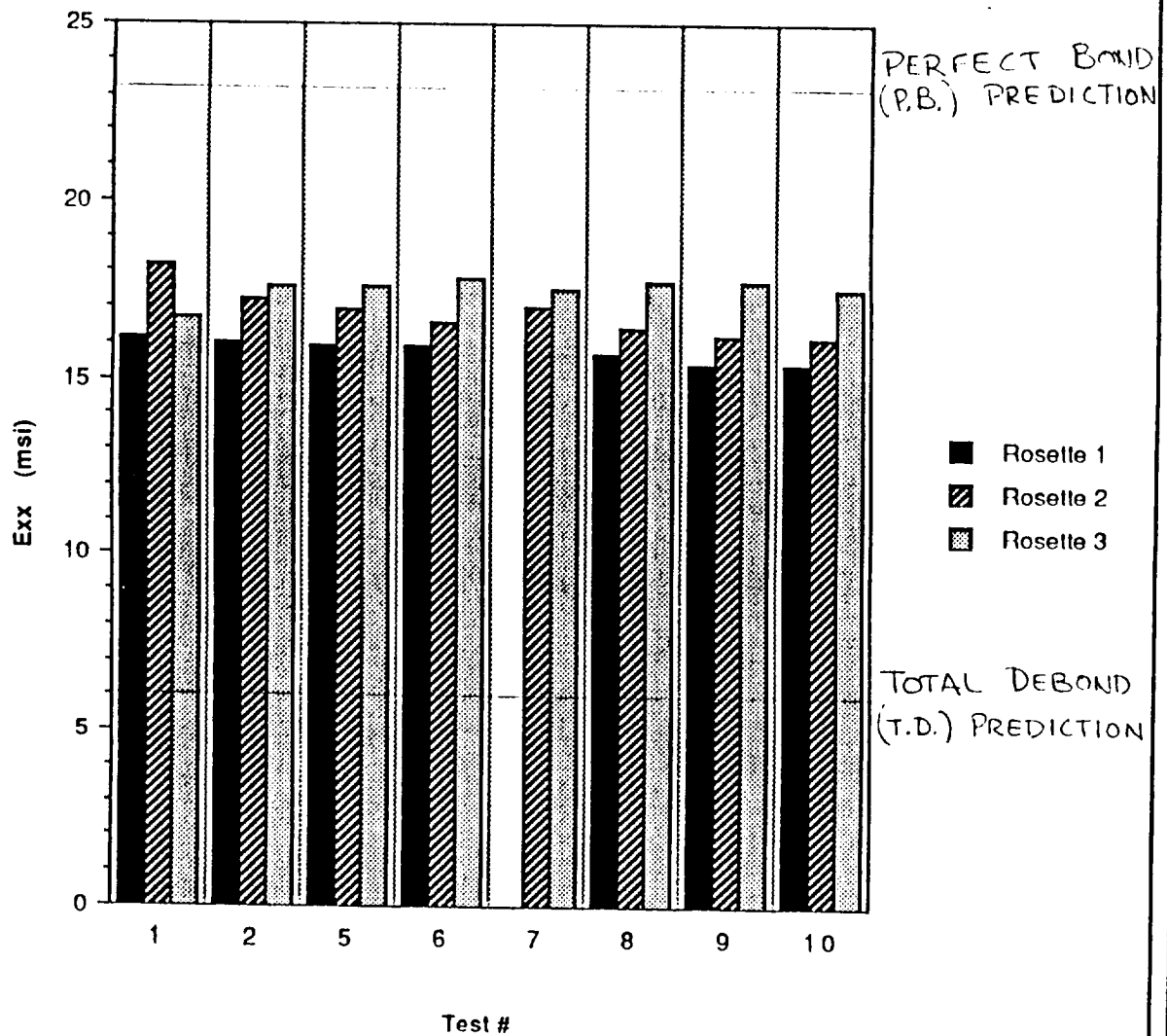


name 59a plot



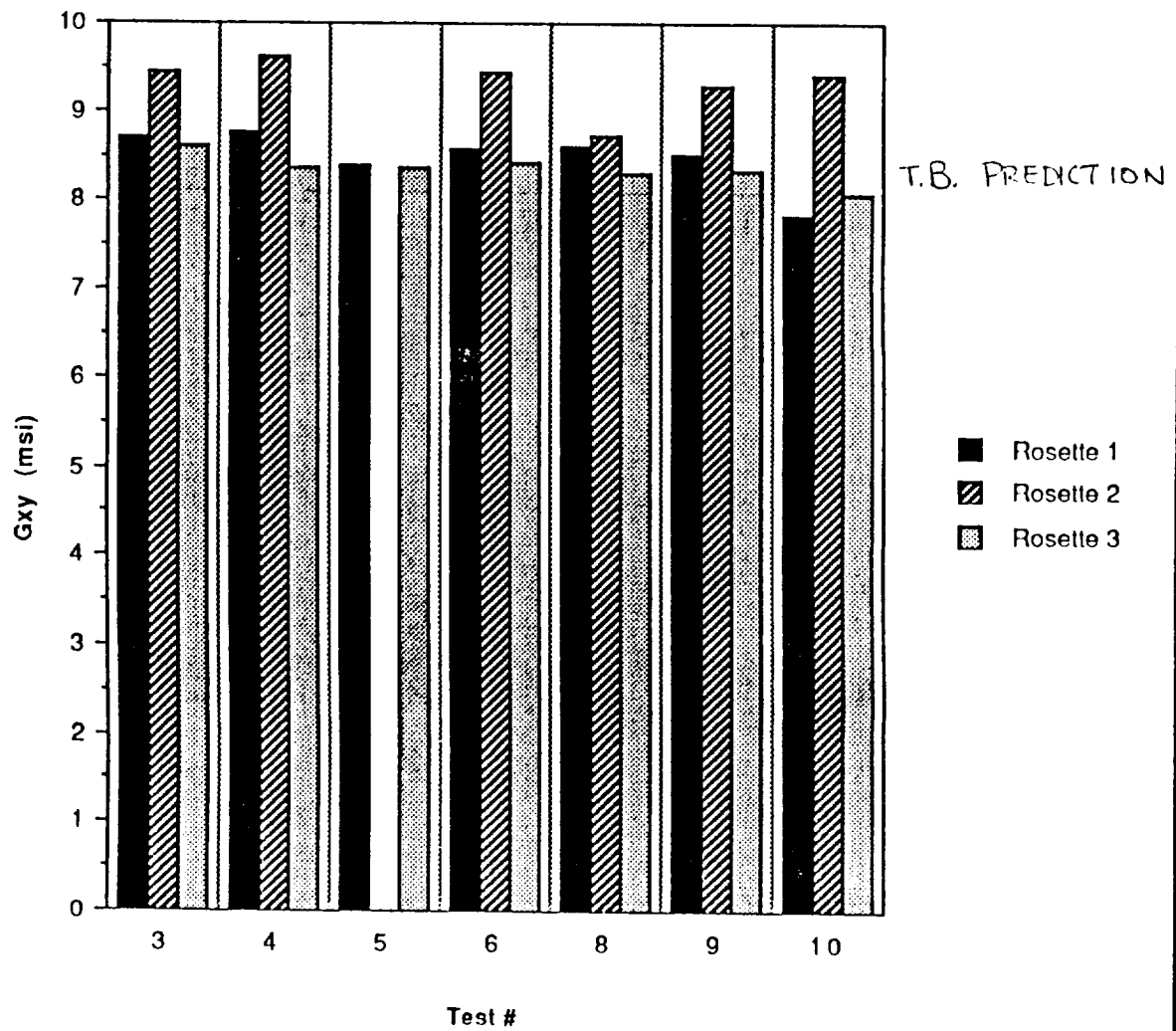
UVA  
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MECHANICS

SCS-6/Ti 15-3 [+45] Specimen #5  
Axial Modulus (Loading)



SCS-6/Ti 15-3 [+45]<sub>s</sub> Specimen #5  
Shear Modulus

P.B. PREDICTION



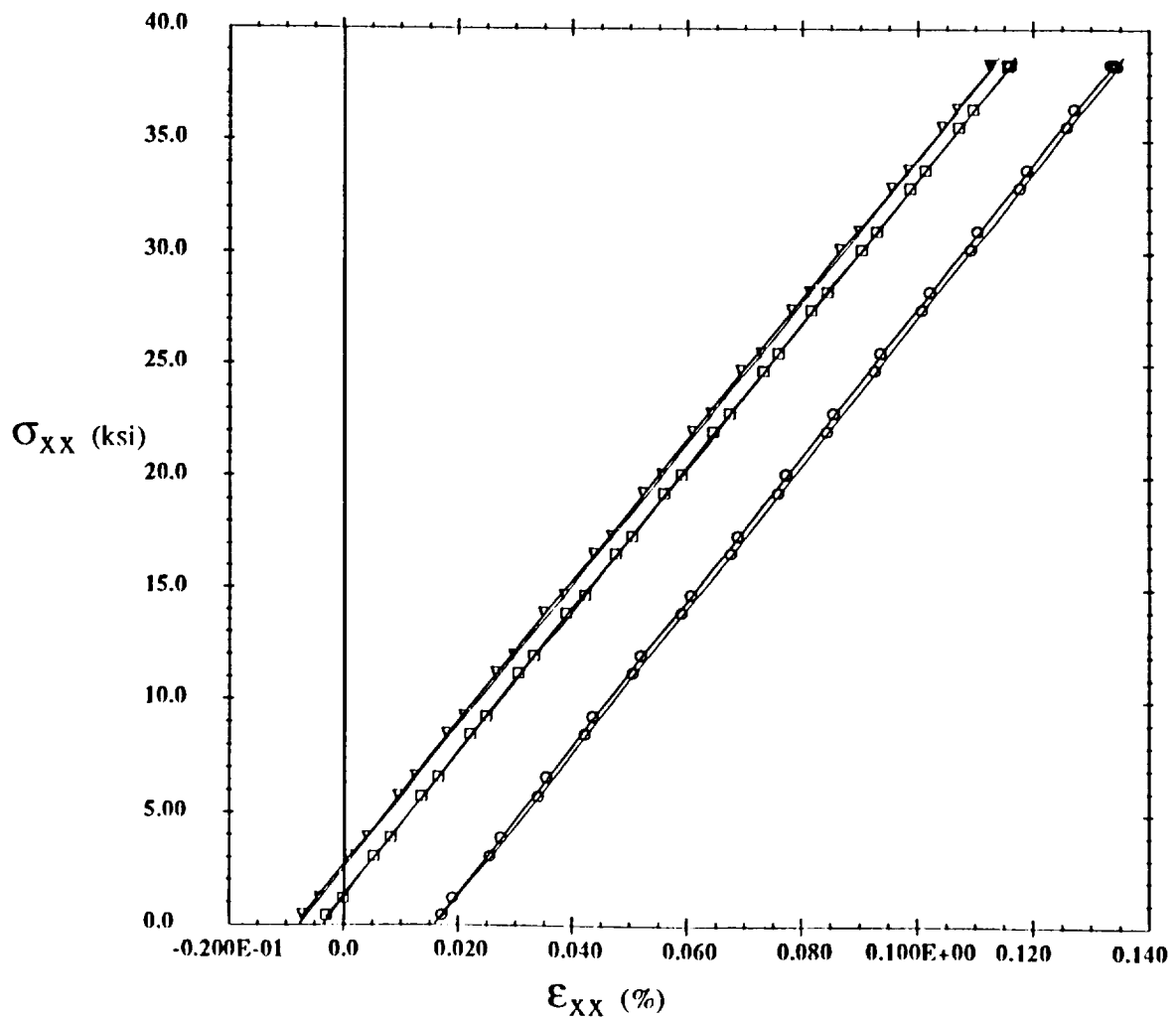
UVA  
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MECHANICS

# SCS-6/Ti 15-3 Axial Stress/Strain

(0<sub>4</sub>)  $\nu_f=0.4$

Speciman#2 Test#11

- ▽— Rosette#1  $E_{xx}=31.60\text{msi}$ ,  $\nu_{xy}=0.265$
- Rosette#2  $E_{xx}=31.96\text{msi}$ ,  $\nu_{xy}=0.300$
- Rosette#3  $E_{xx}=32.44\text{msi}$ ,  $\nu_{xy}=0.309$



runa 211 plot



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MECHANICS

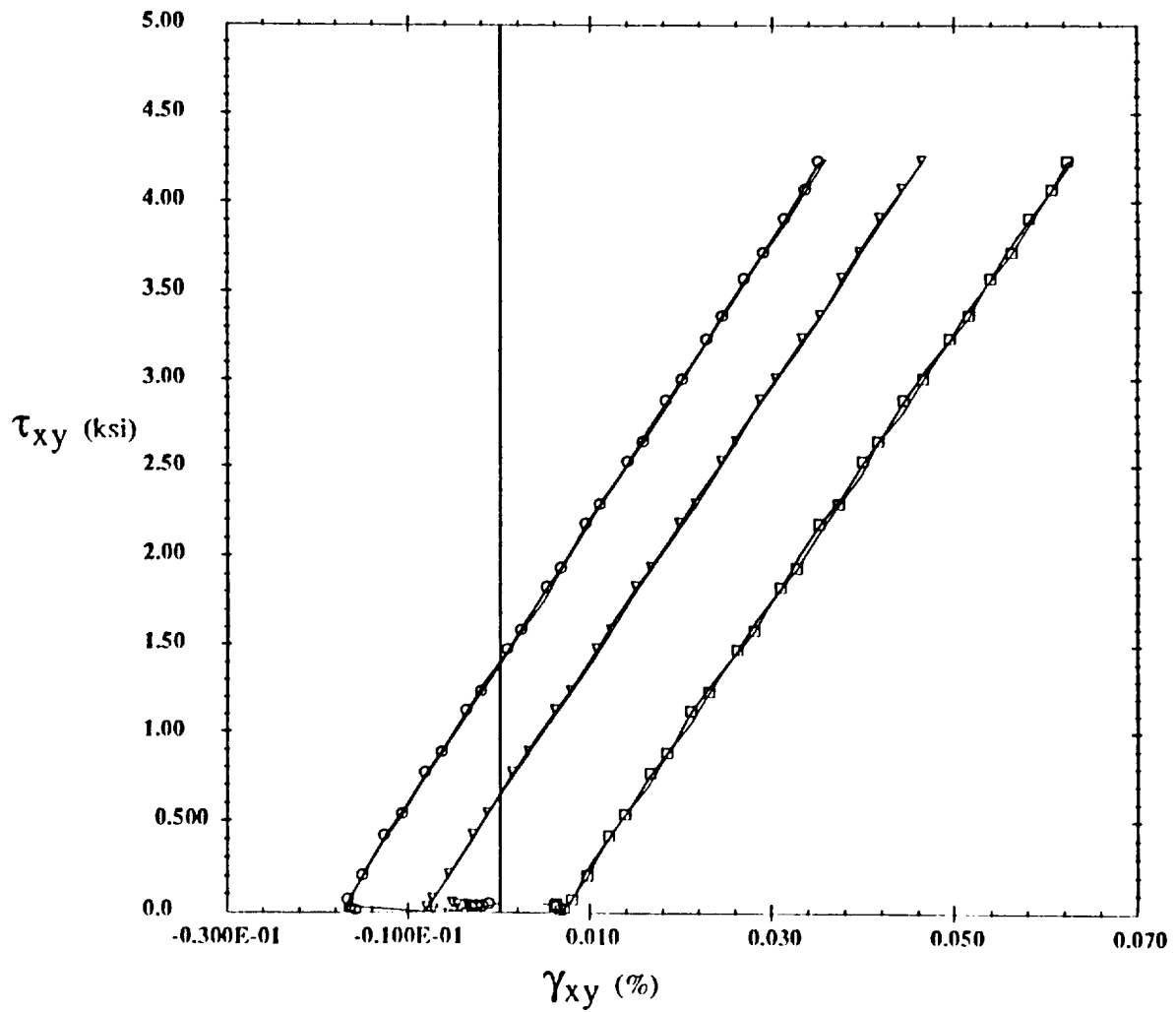


# SCS-6/Ti 15-3 Shear Stress/Strain

(0<sub>4</sub>) V<sub>f</sub>=0.4

Speciman#2 Test#11

- ▽— Rosette#1 G<sub>xy</sub>=7.764msi
- Rosette#2 G<sub>xy</sub>=7.575msi
- Rosette#3 G<sub>xy</sub>=7.984msi

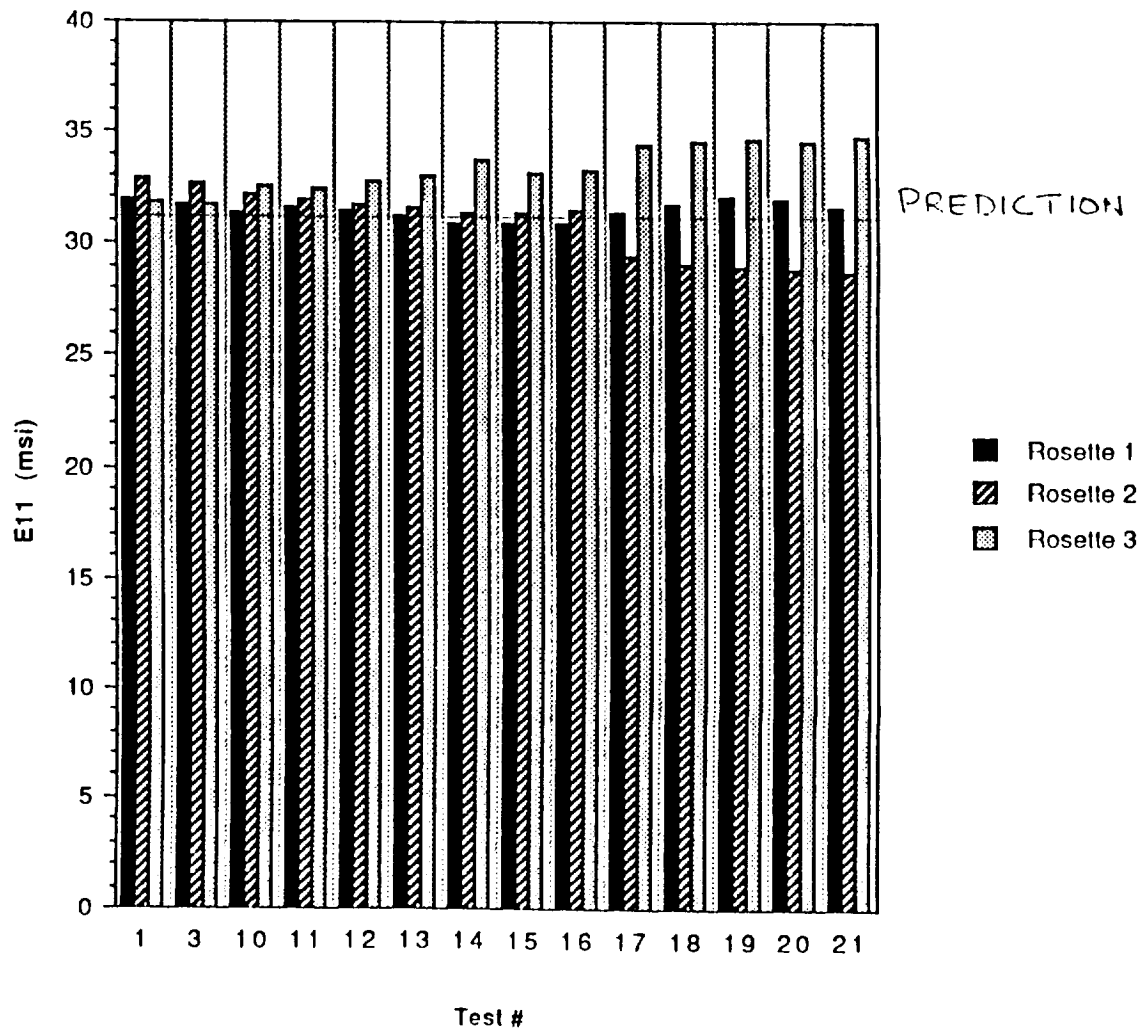


run 211a plot

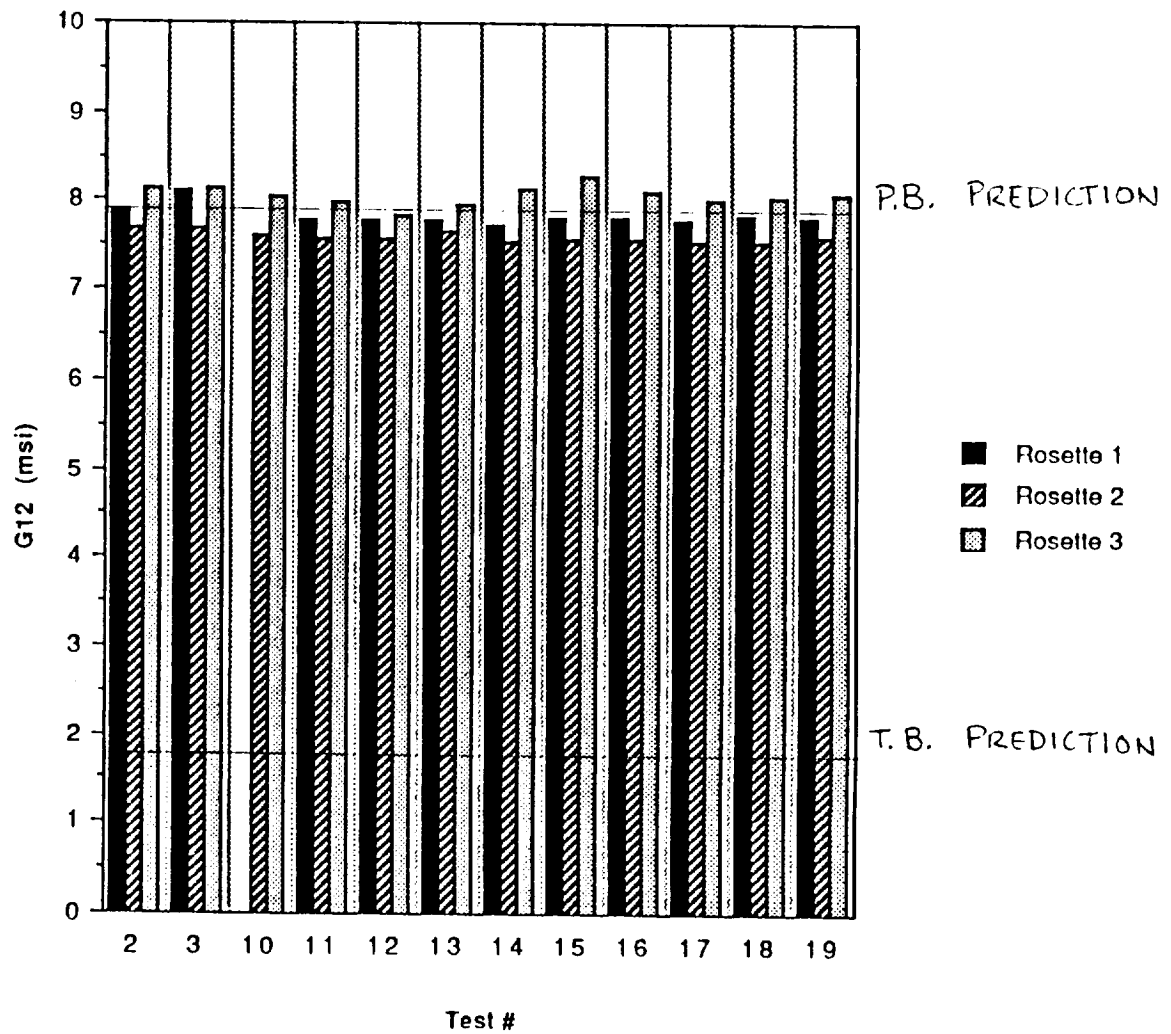


UVA  
APPLIED  
MECHANICS

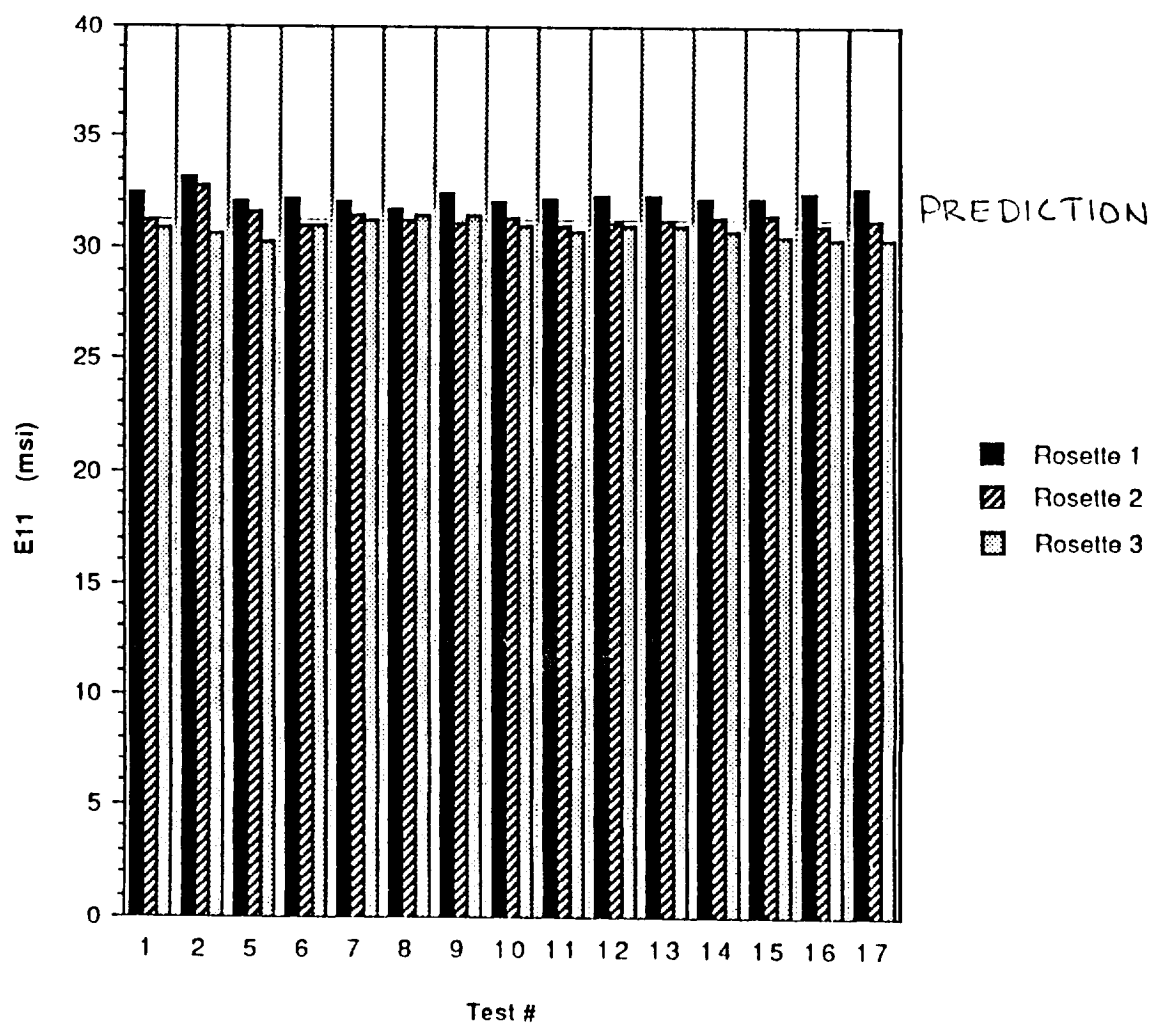
SCS-6/Ti 15-3 [0] Specimen #2  
Axial Modulus (loading)



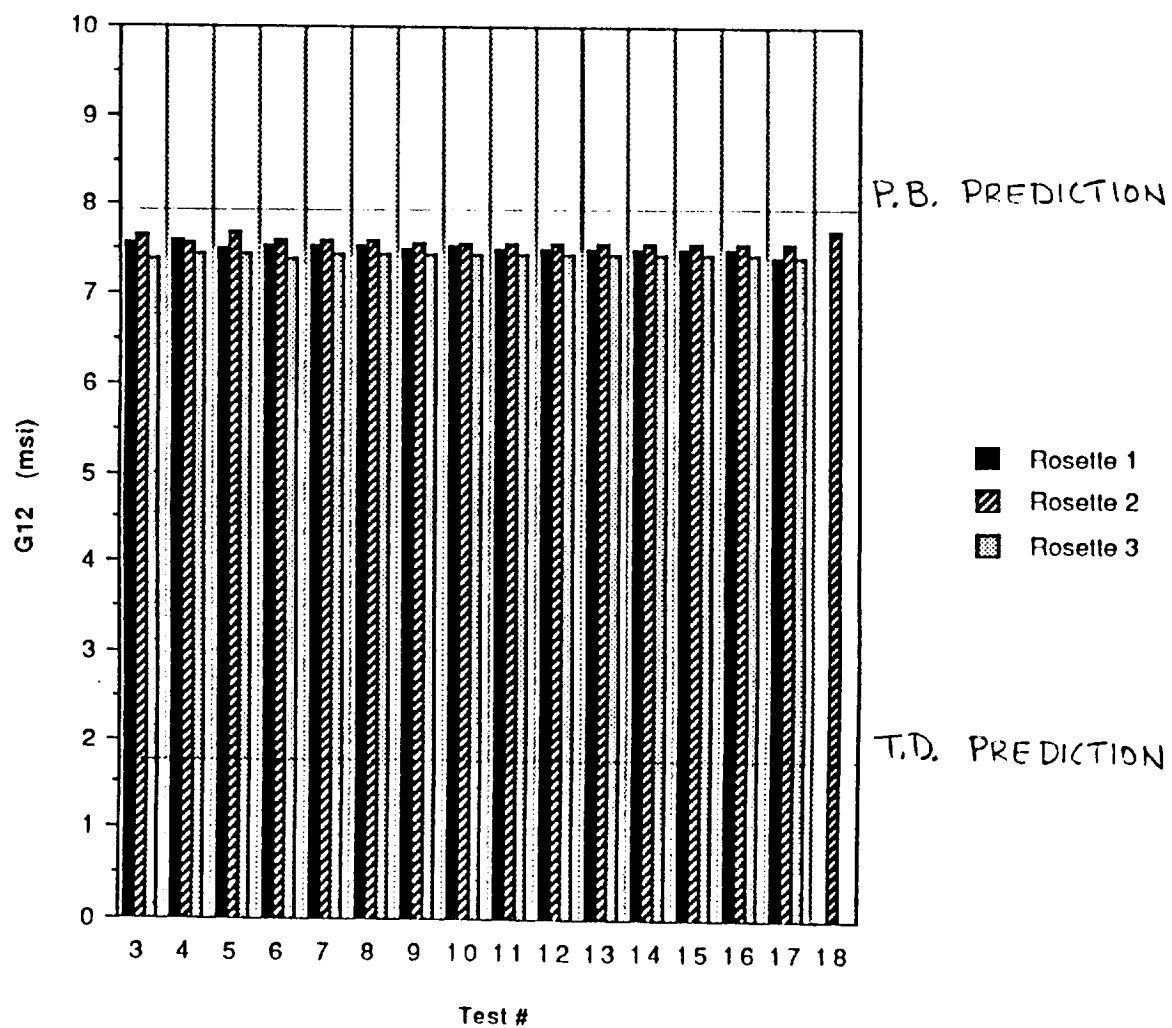
SCS-6/Ti 15-3  $[0]_4$  Specimen #2  
Shear Modulus



SCS -6/Ti 15-3  $[0]_4$  Specimen #4  
Axial Modulus (Loading)



# SCS-6/Ti 15-3 $[0]_4$ Specimen #4 Shear Modulus (Loading)

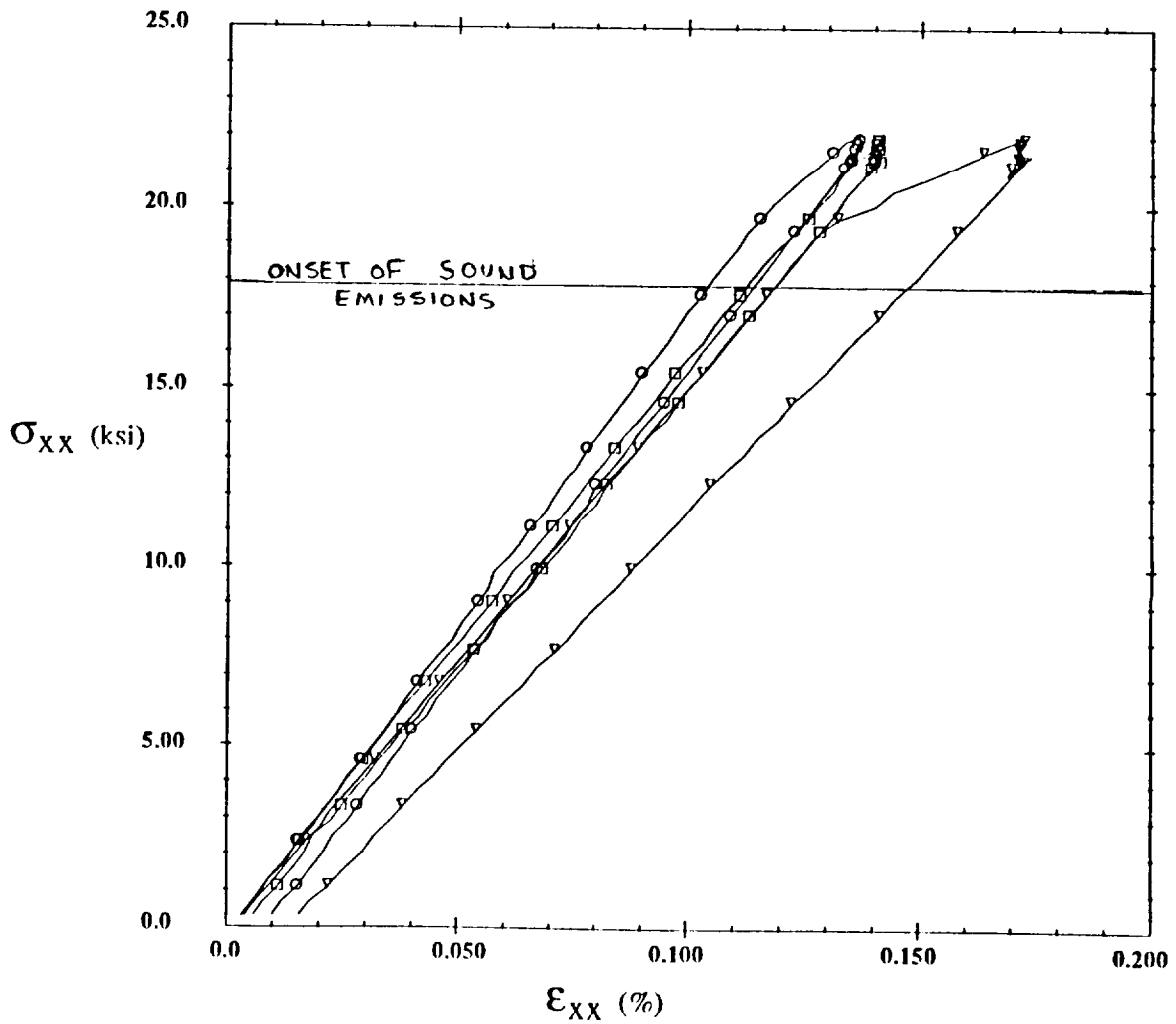


# SCS-6/Ti 15-3 Axial Stress/Strain

$(\pm 45)_s$   $V_f=0.4$

Specimen#5 Test#10

- ▽— Rosette#1  $E_{xx}=15.4\text{msi}$
- Rosette#2  $E_{xx}=16.1\text{msi}$
- Rosette#3  $E_{xx}=17.5\text{msi}$



run 510 plot



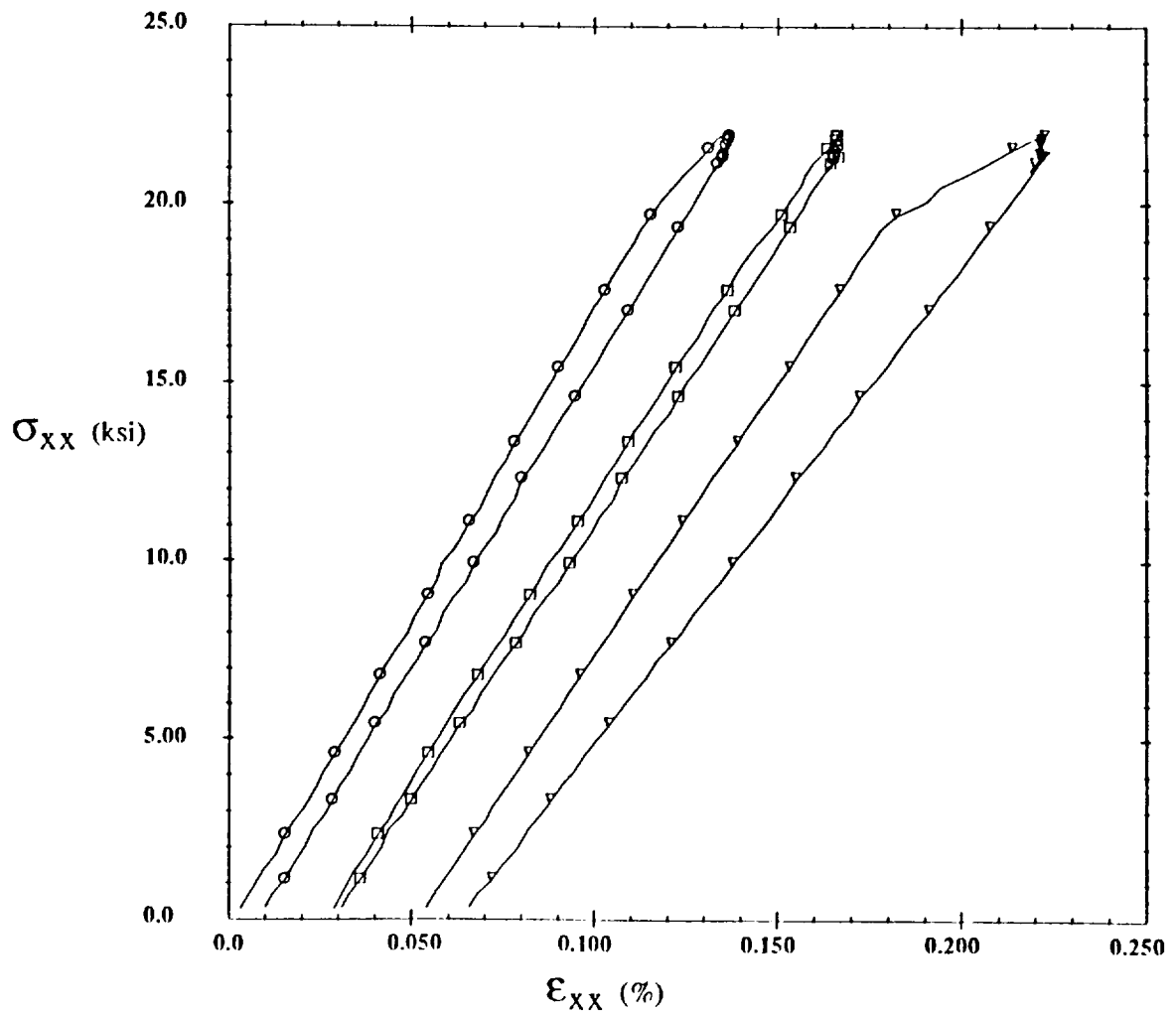
UVA  
APPLIED  
MECHANICS

# SCS-6/Ti 15-3 Axial Stress/Strain

( $\pm 45$ )<sub>s</sub>  $\nu_f = 0.4$

Specimen#5 Test#10

- ▽— Rosette#1  $E_{xx} = 15.4 \text{ msi}$
- Rosette#2  $E_{xx} = 16.1 \text{ msi}$
- Rosette#3  $E_{xx} = 17.5 \text{ msi}$



nam.510b plot



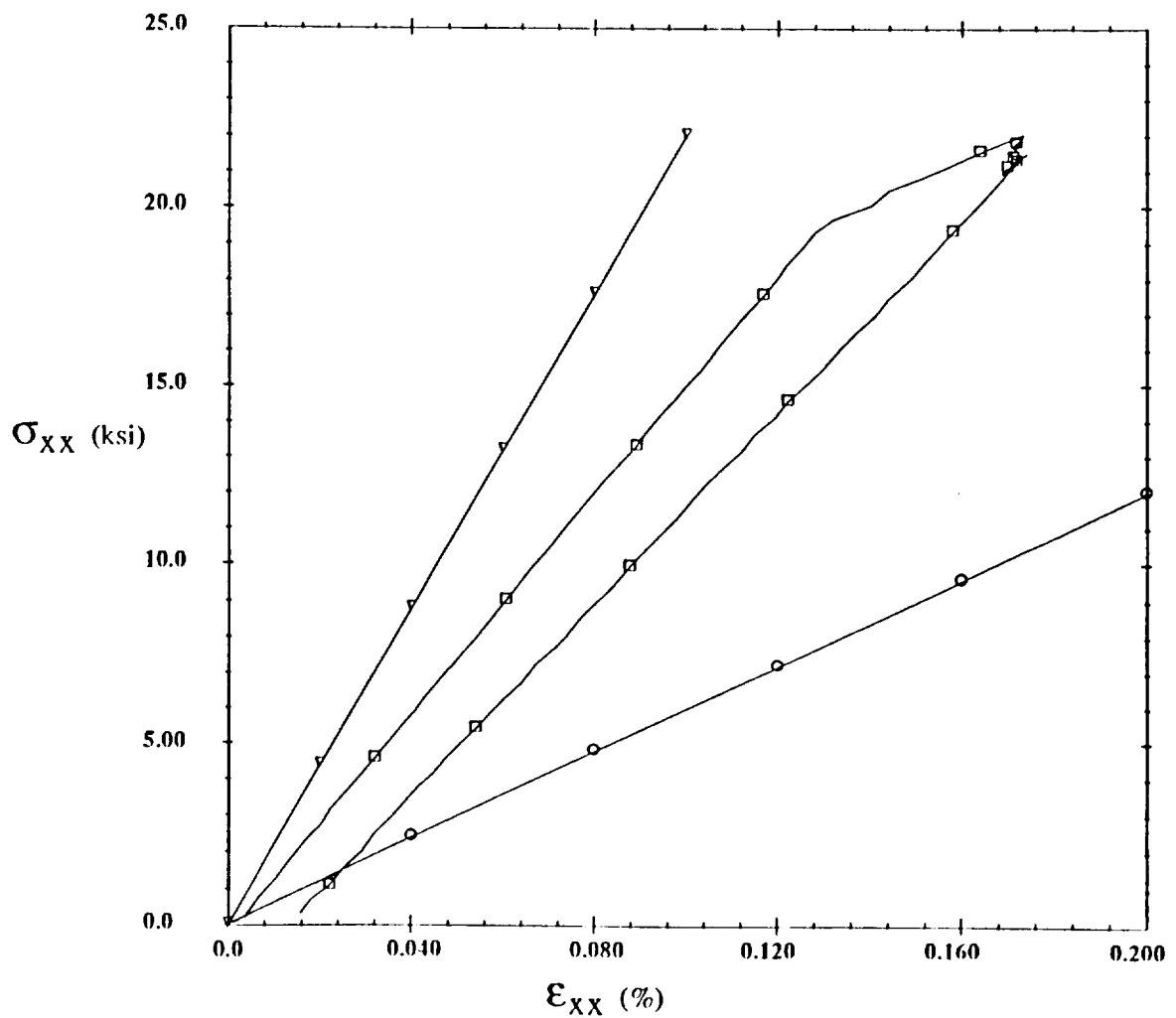
UVA  
APPLIED  
MECHANICS

# SCS-6/Ti 15-3 Axial Stress/Strain

( $\pm 45$ )<sub>s</sub>  $\nu_f=0.4$

Speciman#5 Test#10

- ▽—  $\Delta T=0^\circ\text{F}, R_n=0, R_t=0$
- Rosette#1  $E_{xx}=15.4\text{msi}$
- $\Delta T=0^\circ\text{F}, R_n=0.01, R_t=0.1$



new 510 xl plot



UVA  
APPLIED  
MECHANICS



# SCS-6/Ti 15-3 Shear Stress/Strain

( $\pm 45$ )<sub>s</sub>  $\nu_T=0.4$

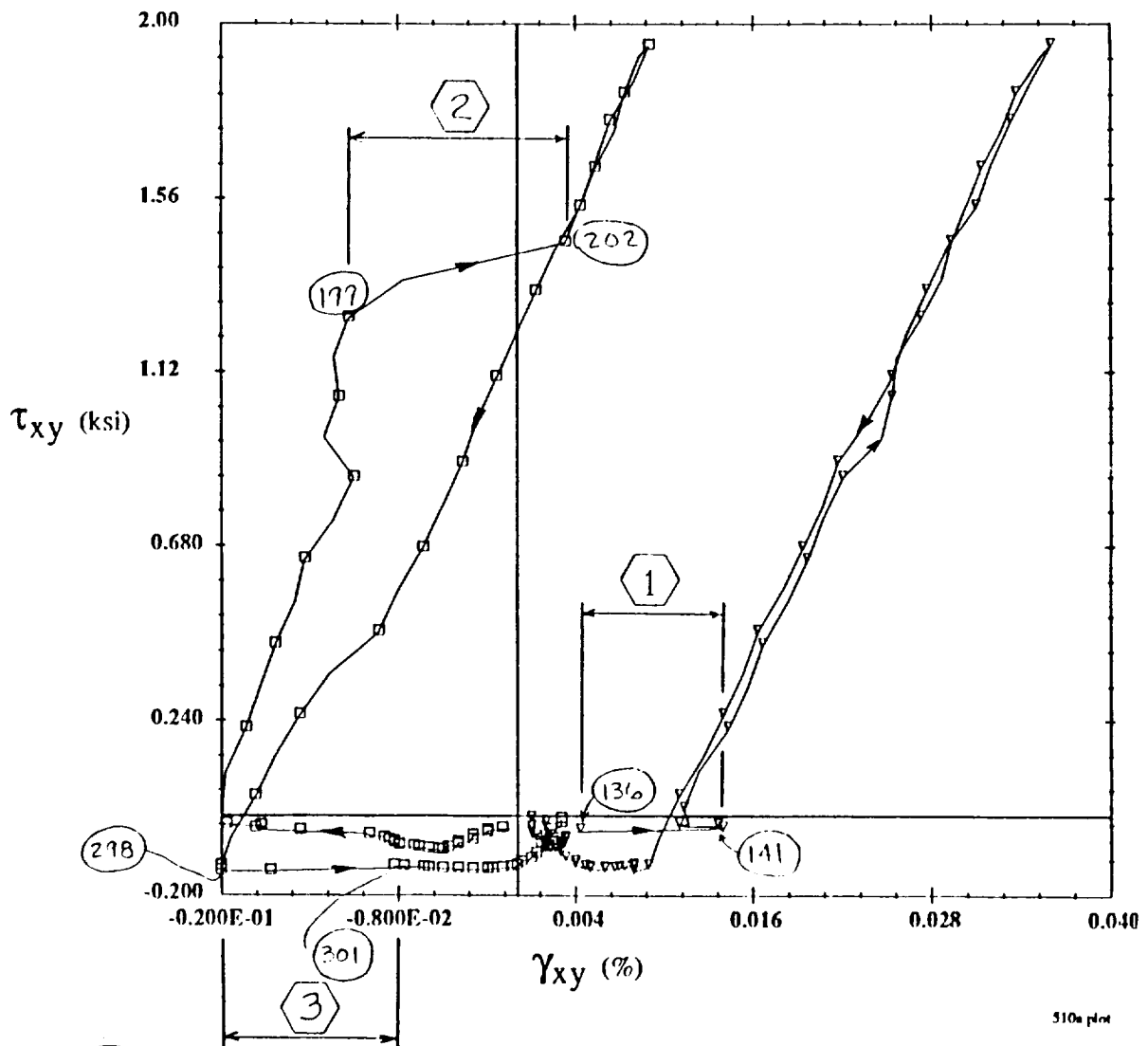
Speciman#5 Test#10

—▽—

Rosette#1

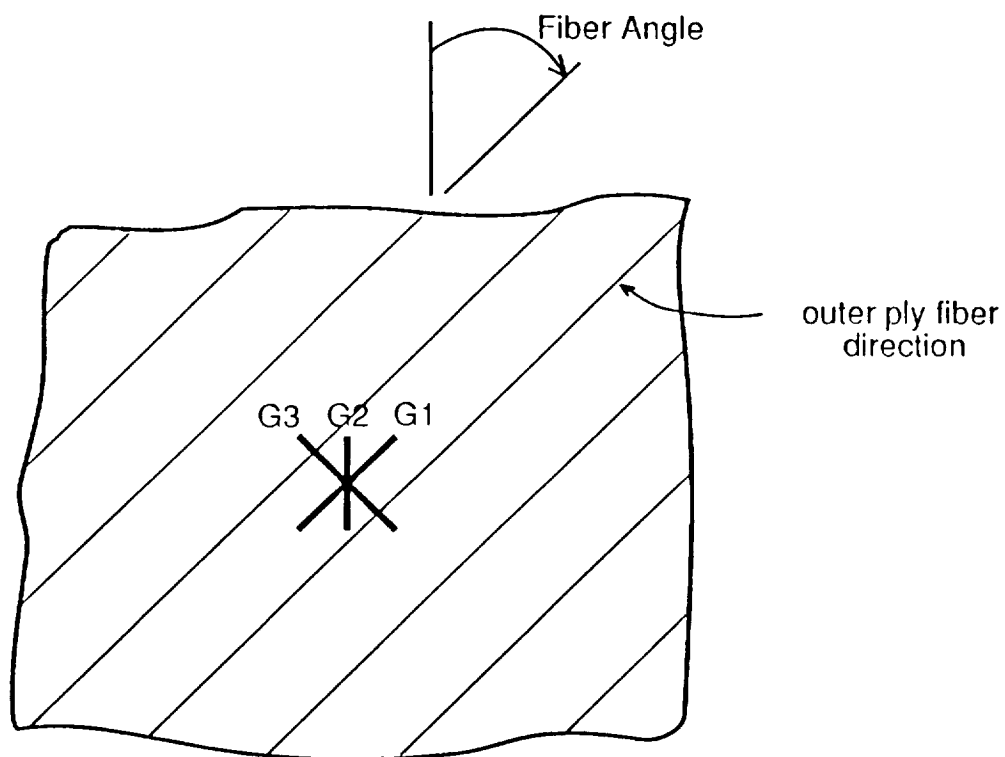
—□—

Rosette#5

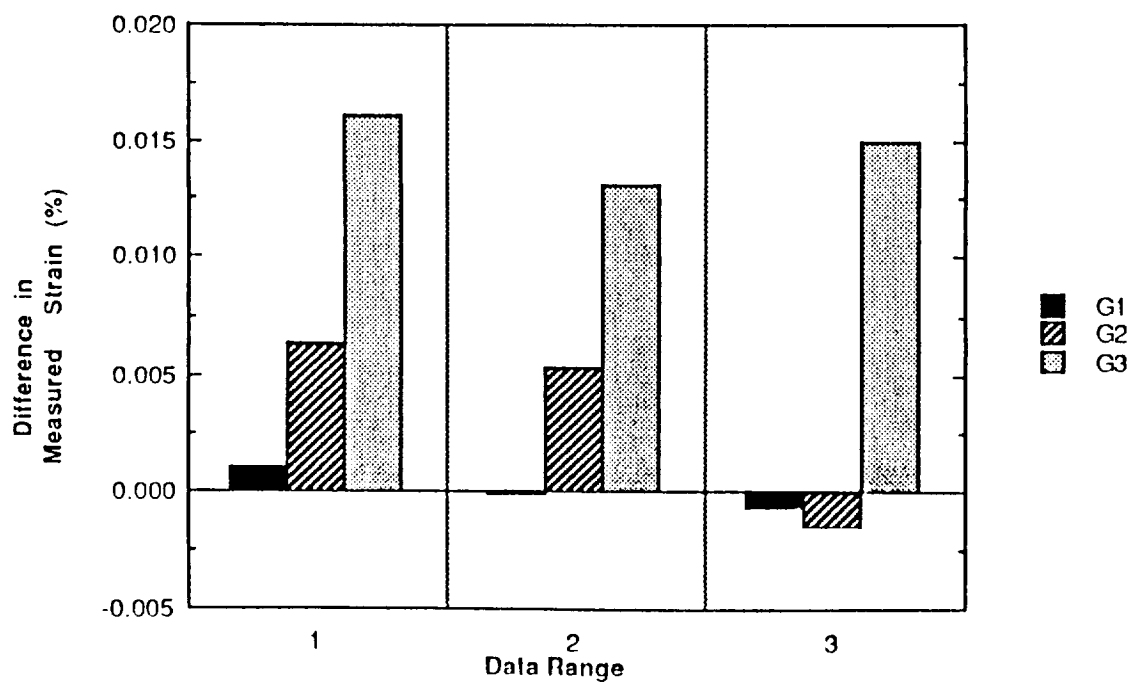


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MECHANICS

## GAGE ORIENTATION



## JUMP IN MEASURED STRAIN

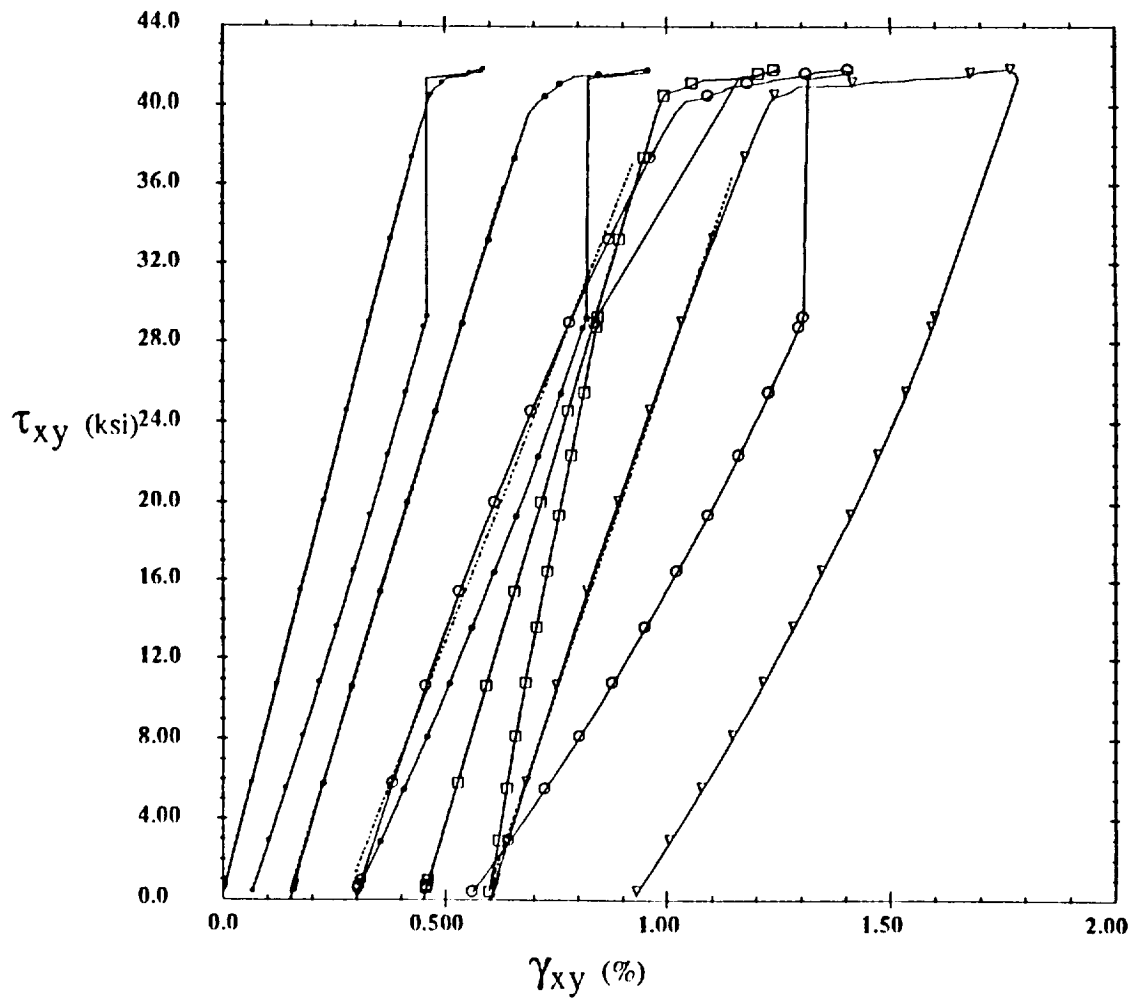


# SCS-6/Ti 15-3 Shear Stress/Strain

$|0|_4 V_f=0.4$

Specimen#4 Test#18

- ▽— Rosette#1  $G_{xy}=6.566\text{msi}$
- Rosette#2  $G_{xy}=7.526\text{msi}$
- Rosette#3  $G_{xy}=5.718\text{msi}$
- Rosette#4  $G_{xy}=7.398\text{msi}$
- ▲— Rosette#5  $G_{xy}=8.735\text{msi}$



at 118 psi

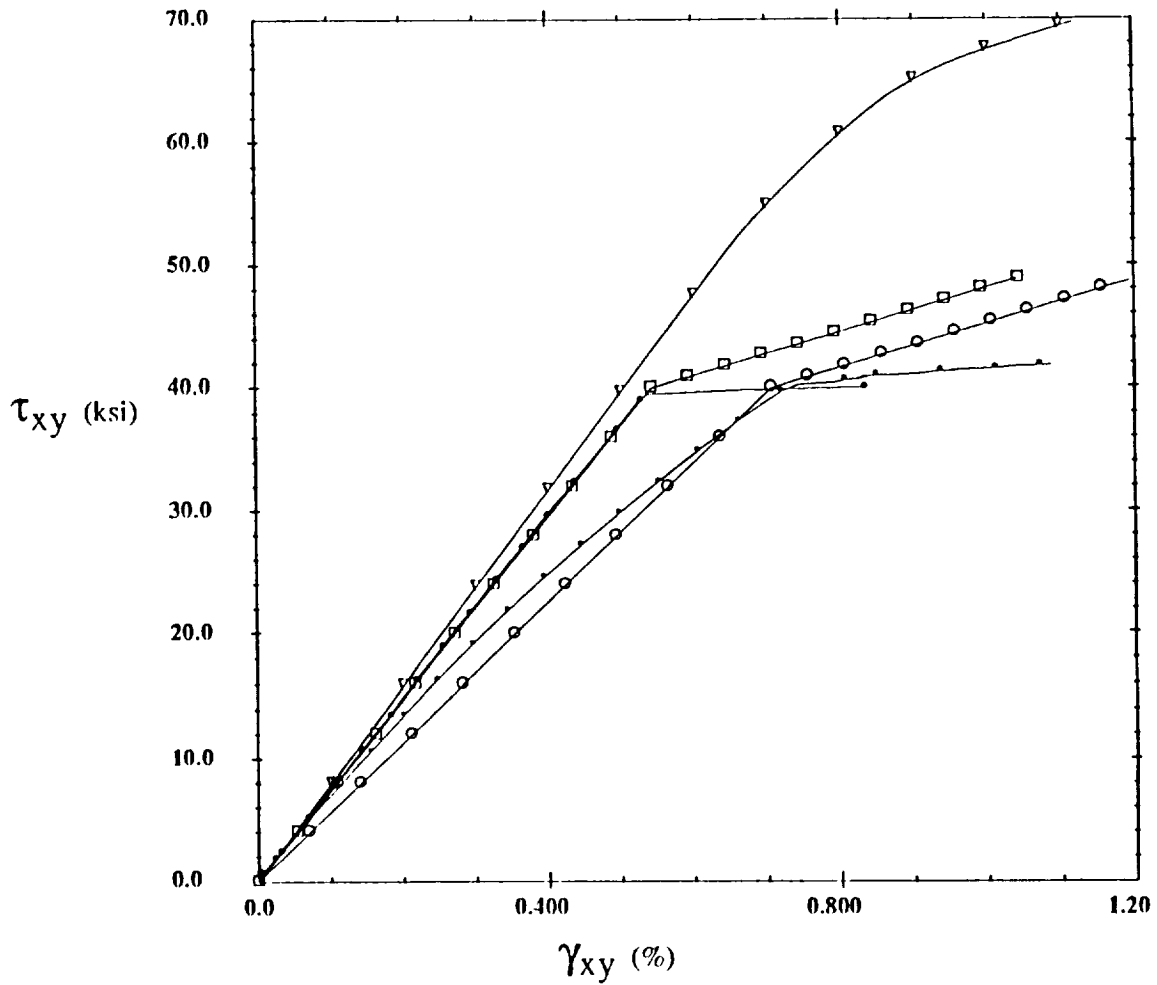


UVA  
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MECHANICS

# SCS-6/Ti 15-3

$[0^\circ]_4$   $V_f=0.4$

- ▽—  $\Delta T=0^\circ\text{F}$ ,  $R_o=0$ ,  $R_i=0$
- $\Delta T=-1000^\circ\text{F}$ ,  $R_o=0.5E-5/1E2$
- $\Delta T=-1000^\circ\text{F}$ ,  $R_o=3E-5/1E2$
- Specimen#4, Test#17, Rosette#3
- ▲— Specimen#4, Test#18, Rosette#3

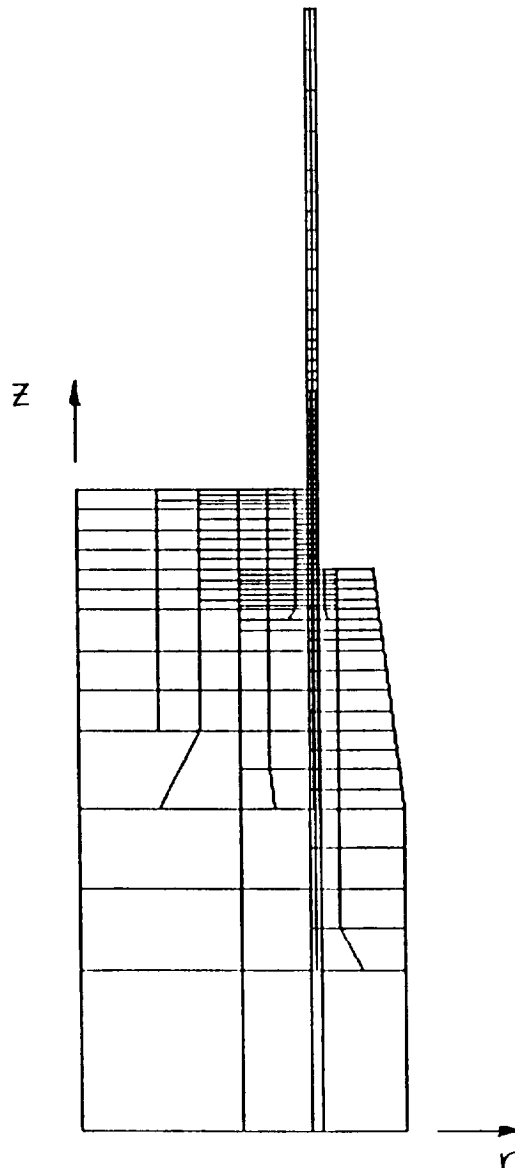


spec4 plot



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# Finite Element Model of $[0]_4$ Tube

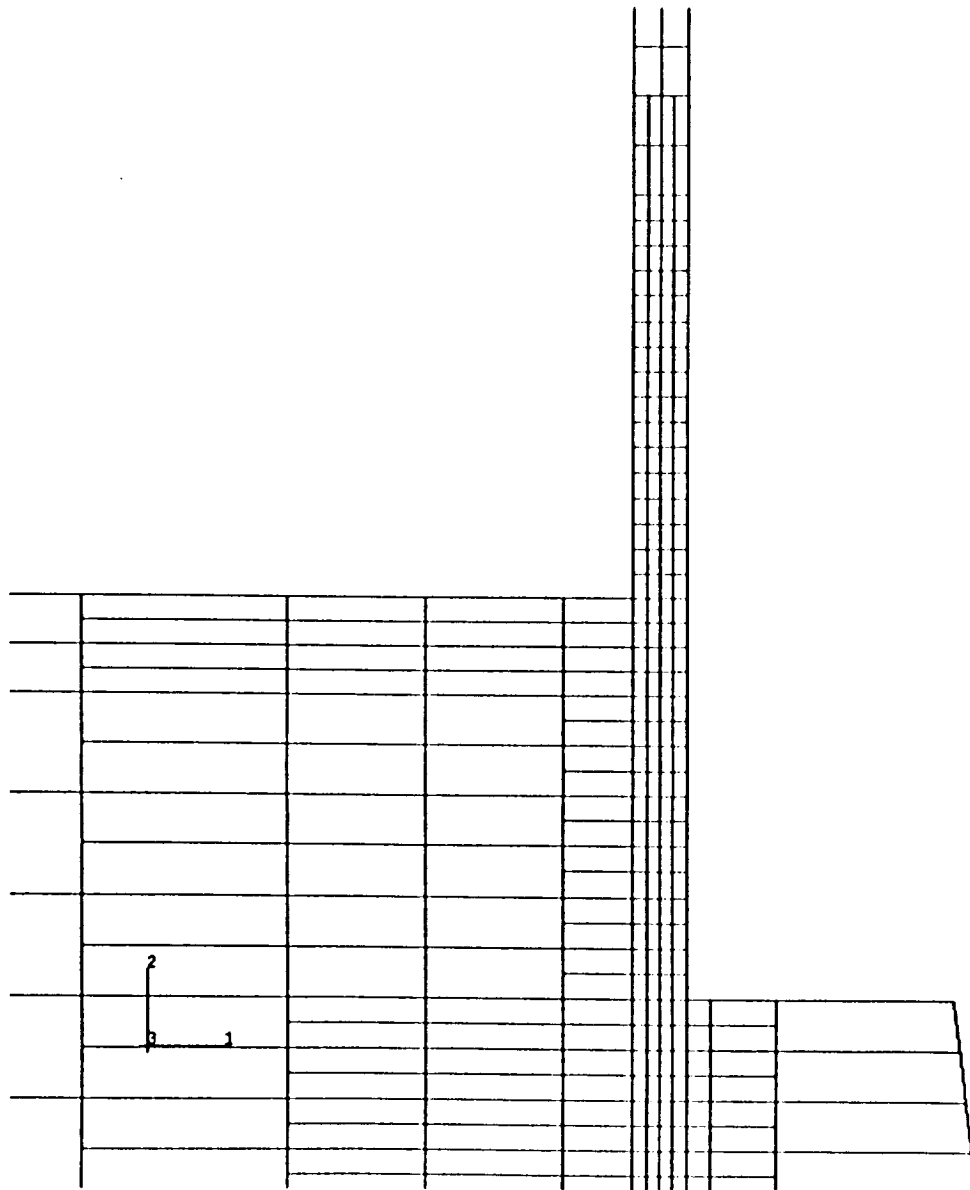


Tube Model-1483 nodes  
434 quad. axisym. elements



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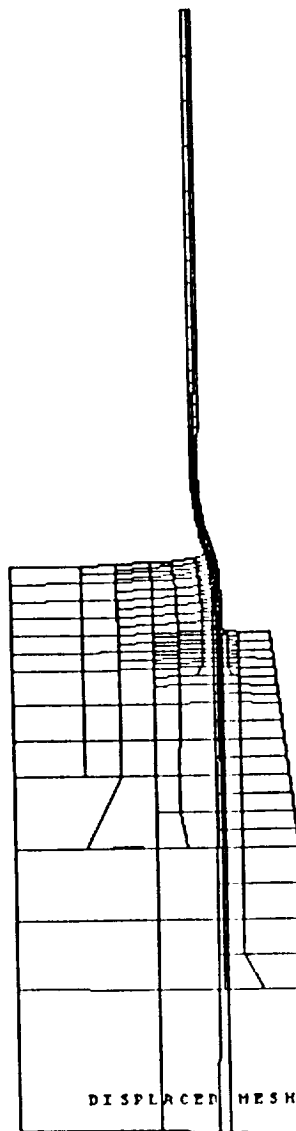
# Finite Element Model of $[0]_4$ Tube



Tube Model Partial Mesh Enlargement



# Finite Element Model of $[0]_4$ Tube Displaced Geometry

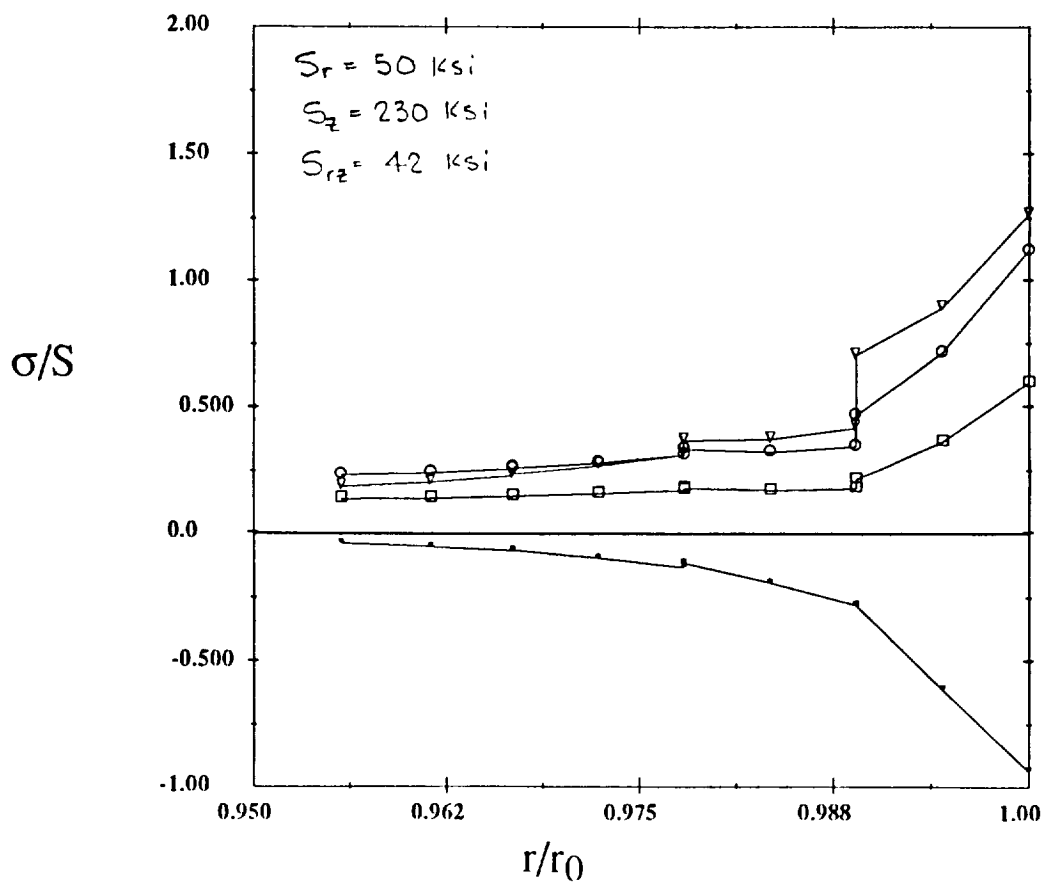
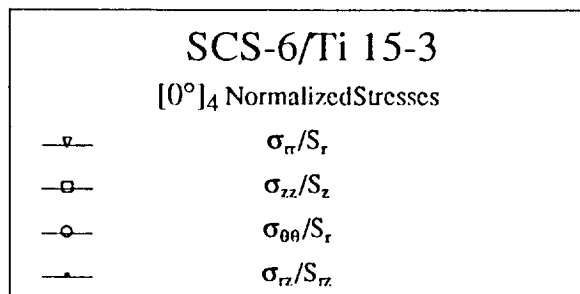


Displacement due to Axial Loading



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# Finite Element Model



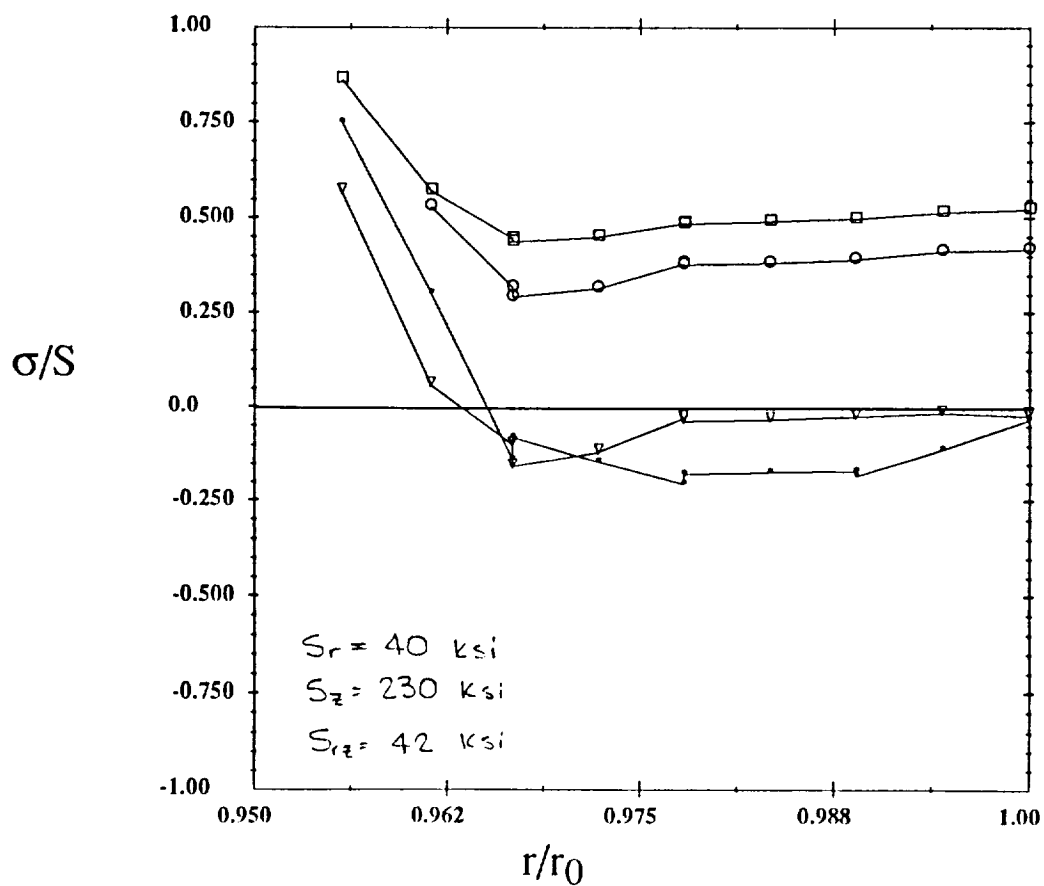
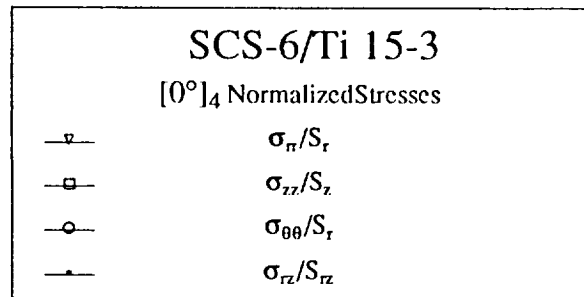
Normalized SiC/Ti Stresses at the top of the plug



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# Finite Element Model



Normalized SiC/Ti Stresses at the top of the fixture



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## Future Work

- Continue testing tubes
  - 2-[0]<sub>4</sub> tubes
  - 6-[±45]<sub>s</sub> tubes
- Enhancements to analytical model



## Conclusions

- Good correlation between theory and experiment for elastic moduli of  $[0]_4$  tube
- Poor correlation between theory and experiment for elastic moduli of  $[\pm 45]_s$  tube
- Stress concentrations due to the fixture cause failure in the  $[0]_4$  tube during tension tests
- No degradation of moduli with damage
- Damage is a local phenomenon
- Nonlinear response of  $[\pm 45]_s$  tube occurred at a stress level of 25% that of predicted initial yielding

